THE THERMAL SENSITIVITY OF THE STOMACH[1]

By EDWIN G. BORING

The problem of the sensitivity of the stomach to thermal stimulation has never been settled.[2] Lennander denied all sensitivity to the stomach, and Müller failed to find thermal sensitivity. Weber, who could get only delayed coolness and warmth, was inclined to attribute the sensations to the skin of the abdomen. Hertz, Cook, and Schlesinger were unable to obtain temperature sensations from the stomach. They held that the apparent occurrence of such sensations with some subjects could not be due to conduction to the skin, but might be explained as the result of stimulation of the esophagus. In general, those who deny the thermal sensitivity of the stomach explain its apparent sensitivity under certain conditions as the result of stimulation (either by conduction or by chance contact) of the skin, of the body-wall, of the parietal peritoneum, or of the esophagus. Hertz states that the stomach is "rarely, if ever," sensitive to heat and cold. Meumann, on the other hand, insisted upon a general and well-differentiated stomachic sensibility. Becher, at first upholding the hypothesis of Lennander, reversed his judgment in regard to thermal sensitivity as the result of further experimental work. Quincke, Neumann, and Roux have all described cases of sensitivity to warmth and cold. It should be observed that even those writers who deny the sensitivity of the stomach to cold and hot stimuli find a 'warmth' or a 'burning sensation' which is elicited in the stomach by chemical stimuli. Meumann, Becher, Müller, and Hertz, Cook, and Schlesinger have observed this 'warmth.'

[1] From the Psychological Laboratory, Cornell University.

[2] For discussions of conflicting results and for references to the names mentioned, see E. Becher, Einige Bemerkungen über die Sensibilität der inneren Organe, *Arch. f. d. ges. Psychol.*, 15, 1909, 361ff.; A. F. Hertz, F. Cook, and E. G. Schlesinger, The Sensibility of the Stomach and Intestines in Man, *Jour. Physiol.*, 37, 1908, 481ff.; A. F. Hertz, The Sensibility of the Alimentary Canal, 1911, 5ff.; and E. G. Boring, The Sensations of the Alimentary Canal, *Amer. Jour. Psychol.*, 26, 1915, 2ff.

The present writer has described experiments[3] in which warmth and cold were brought out by the introduction of warm and cold water into the stomach through a stomach-tube. The sensations came usually after a slight delay; the delay was less for the greater extremes of temperature; and the temperature of the water, when injected, had to be very much more extreme, if it was to produce sensation, than would a stimulus upon the outside of the body. These facts seemed to indicate that the sensory organs might be remote from the stomach and be stimulated through conduction. The qualitative identity of the cutaneous sensation and the sensation brought out by internal stimulation, if it does not positively support such a view, at least presents no objection to it. Accordingly the writer was inclined to accept the notion that these sensations do not originate in the stomach, although he promised at that time a further study. It was with this promise in mind that the experiments described below were undertaken. The fact that the conclusion on the basis of more recent work is in part a reversal of the writer's earlier belief is a demonstration of the value of the refinement of technique.

It was the object of these experiments to obtain a continuous record of temperatures within the stomach and to parallel that record by a contemporaneous report of sensation. It seemed that, if thermal sensations were aroused only after the conduction of heat from or to the stomach, it might be possible to arrange conditions so that the sensation would appear only *after* the most extreme temperature had been reached in the stomach. No such conditions were, as a matter of fact, found.

Procedure and Apparatus.—In all but two trials the writer (B) acted as subject. In two trials (W6, C6) Mr. F. L. Dimmick (D) was subject. In previous experiments[4] D had given evidence of being less sensitive to stomachic thermal stimulation. His observation here was intended as a check upon that of B.

As stimulus hot or cold water was introduced under air-pressure into the stomach though a stomach-tube. The apparatus has been described elsewhere.[5] The tube in the regular trials was swallowed until a mark 50 cm. from the end came opposite the teeth. In this position the end was undoubtedly well within the stomach. The lower end of the

[3] *Op. cit.*, 40ff.
[4] *Loc. cit.*
[5] *Loc. cit.*

esophagus in B is about 43 cm. from the teeth. The tube was not introduced further, because at 55 and 60 cm. it pressed against the stomach-walls sufficiently to cause discomfort and incipient vomiting. It was also found that in the lower positions the end could sometimes be felt pressed against the body-wall,—a degree of proximity to the superficial tissue that was considered undesirable in these experiments.

In addition to the preliminary trials, which were made with warm water and on B and which served to practise both observer and experimenters, there were seven trials with warm stimuli (W1 to W7) and seven with cold (C1 to C7). The warm stimulus, except in trial W7, was 25 cc. of water at 60° C. The cold stimulus, except in trial C7, was 25 cc. at 0° C. (*Cf.* Tables I and II.) In W7 and C7 less extreme temperatures (27° C for cold, 47° C for warmth) and greater amounts of water (75 cc.) were used. The first four trials of the W series were given successively, separated by short intervals, upon an empty stomach (3 hrs. after eating, 2 hrs. after drinking). The first four trials of the C series were given under like conditions on another day. Trials W5 and C5 with B, and W6 and C6 with D, were given together at another time. B's stomach was empty, D's only partially. W7 and C7 took place on an empty stomach at a fourth session.

Stomachic temperatures were measured by means of a thermo-couple of copper and constantan. The wires to one junction were led through a small rubber tube, which in turn passed within the lumen of the stomach-tube. The water was blown through the stomach-tube, but outside the inner tube containing the wires. The thermo-electric junction was fastened flush with the end of the stomach-tube. The other junction was kept in a covered vessel of boiling water.[6] The difference of electric potential was read on a small d'Arsonval galvanometer with external scale and telescope.[7]

The record of every trial was made on a kymograph. An electric time-marker, connected with a metronome,[8] wrote seconds. In its circuit there was an electric bell, which was ordinarily short-circuited by a switch. The experimenter opened this switch during the time that

[6] Hence correction for barometer had to be made for the results of each session.

[7] The galvanometer was a cheap instrument and required adjustment before it could be relied upon. During the experiments its zero shifted by an amount equivalent to 2°C. A calibration taken after the series gave, however, a curve exactly parallel to the one taken before. Temperatures were therefore computed for each session with reference to the zero of the galvanometer for that session. Three calibrations taken at the same time gave a maximal deviation equivalent to 0.4°C.

[8] The metronome showed a variable error of 1.5% and a constant error of 2.9% in 10 trials of 100 secs. each. Results were corrected for the constant error.

he was squeezing the bulb which forced the water into the stomach. The intermittent current, which resulted from placing the bell in circuit, made the time-marker write an alternately broad and narrow line, which indicated, besides the seconds, the duration of the time required to introduce the stimulus. A second signal-magnet was connected with two keys under the control of the person who read the galvanometer. The one key caused a simple depression of the signal; the other, connected through a second electric bell, made the marker vibrate so as to write a broad line. The experimenter, set to read the galvanometer, signalled with the second key whenever the cross-hairs of the telescope crossed one of the main scale divisions (*i. e.*, one of those five divisions apart). He signalled with the other key for the intermediate divisions, except when the change was too rapid for him to catch all the divisions; in such places the intermediate divisions were left out. A third line was written by a tambour, connected with a rubber bulb which the observer squeezed to indicate when he felt temperature sensation.[9]

Two experimenters were required, one to manipulate the apparatus and one to read the galvanometer.

Several possible sources of error should be noted. (1) It was not possible to use a double-walled stomach-tube, since the lumen had to be large enough to contain the tube through which the wires ran and still to allow space for the water to pass.[10] The danger arising from the lack of this precaution is not as great as might appear, because it has already been shown that the thermal sensations, which it is the object of this study to explain, occur when a double-walled tube is used. In general the 'stomachic' warmth and cold are referred lower down than the esophageal, although they may also spread to the throat and chest;[11] and the sensations reported in these trials showed this same stomachic pattern of reference. (2) A variable error of the galvanometer has been mentioned. Readings should, perhaps, not be considered as accurately indicating absolute temperature to less than 0.4°C. (3) The errors of the metronome are negligible, especially as the absolute times are of little importance. (4) The reaction times of the experimenter who read the galvanometer are involved in the results. It is impossible to say how accurate he was. Doubtless his error is considerable in the cases where the temperature was changing very rapidly just at the introduction of the stimulus. The large M.V. for the temperature at which sensation first appears (p. 493) indicates that these early temperatures are less accurate. The error should be negligible for the gradual change in the later parts of a trial.

Results.—In order to render the results comparable, temperature curves were platted between time and temperature

[9] In the first experiments this same tambour was used to indicate the duration of the giving of the stimulus. Sensation, however, appeared so soon that the two curves were apt to interfere; hence the method described above was adopted.

[10] The actual tube used was the stethoscope tubing of Tube No. 3, *op. cit.*, p. 6; outside diam. 9 mm.; lumen, 5 mm. The wires ran through a tube 4 mm. outside diam.

[11] *Op. cit.*, 20, 42.

for every trial.[12] The observed points, except where some readings were not recorded during the rapid change of temperature in the first few seconds, were about one-half of a degree apart. The interpolated temperatures must then, except where the change was rapid, have been sufficiently accurate, perhaps to 0.1° C. In Tables I and II will be found the temperatures of the stomachic contents as read off from the platted curves at intervals of two seconds. Those temperatures at which there was a report of warmth or cold (as written by the tambour) are printed in heavy-faced type. In some cases, it will be observed, the thermal sensation disappeared for a few seconds and then reappeared again. Nearly all the trials ran beyond 40 secs., sometimes to 60 or 70. No reports of sensation, except in one preliminary trial, occurred so late.

TABLE I

STOMACHIC WARMTH. Figures show variation of stomachic temperature (°C) at different times (secs.) after beginning of introduction of stimulus. **Heavy-faced type** indicates temperatures at which a thermal sensation was felt. End of tube, 50 cm. from teeth.

No. Trial:	W1	W2	W3	W4	W5	W6	W7
Observer:	B	B	B	B	B	D	B
Amt. stim.: cc.	25	25	25	25	25	25	75
Temp. stim.: °C.	60	60	60	60	60	60	47
Seconds	Temperature: °C.						
0	37.0	37.0	37.0	37.0	37.0	37.0	37.0
2	37.0	37.0	37.0	37.1	37.0	37.0	37.7
4	37.0	37.2	37.4	**37.5**	37.5	37.6	38.2
6	**41.9**	41.8	**41.0**	**41.5**	**39.0**	**38.9**	39.5
8	**42.0**	**42.2**	**42.4**	**42.2**	**40.1**	**39.2**	**40.6**
10	**42.0**	**42.5**	**42.9**	**42.6**	**40.4**	**39.6**	**41.1**
12	**41.9**	**42.6**	**43.0**	**42.8**	**40.5**	**39.7**	**41.4**
14	**41.9**	**42.5**	**42.8**	**42.8**	**40.5**	**39.6**	**41.5**
16	**41.9**	**42.3**	**42.1**	**41.8**	**40.5**	**39.2**	**41.5**
18	**41.9**	**42.2**	41.5	**41.3**	**40.5**	**39.0**	**41.5**
20	**41.9**	**42.1**	41.0	**41.1**	**40.5**	38.8	**41.5**
22	**41.8**	**42.0**	**40.6**	**40.9**	40.4	38.7	**41.3**
24	**41.7**	**41.8**	**40.4**	40.6	40.4	38.6	**41.1**
26	41.5	**41.7**	**40.3**	40.4	40.4	38.5	40.9
28	41.2	**41.5**	**40.2**	40.2	40.3	38.4	40.7
30	40.9	41.4	**40.1**	40.0	40.2	38.3	40.5
35	**40.5**	41.1	39.9	39.7	40.1	38.1	40.3
40	40.1	40.9	39.8	39.4	39.9	38.0	40.1

[12] Fairly smooth curves were drawn through all points. These curves departed appreciably from the straight lines connecting the points only during the first few (6-10) secs. The only wide departure allowed here was in conformity with the shape of all the other curves in which intermediate points were recorded.

TABLE II

STOMACHIC COLD. For interpretation, see Table 1.

No. Trial:	C1	C2	C3	C4	C5	C6	C7
Observer:	B	B	B	B	B	D	B
Amt. stim.: cc.	25	25	25	25	25	25	75
Temp. stim.: °C.	0	0	0	0	0	0	27
Seconds	Temperature: °C.						
0	37.0	37.0	37.0	37.0	37.0	37.0	37.0
2	37.0	37.0	37.0	36.9	36.8	36.8	37.0
4	**36.8**	35.4	35.5	35.0	35.3	33.6	33.2
6	**34.7**	27.7	27.4	**27.0**	**28.0**	29.2	**30.7**
8	**24.9**	23.3	**22.7**	**22.9**	**24.9**	29.0	**29.6**
10	**23.7**	**19.5**	**20.1**	**22.3**	**23.8**	**28.8**	**29.5**
12	**23.1**	**19.8**	**19.3**	**22.2**	**23.2**	**28.6**	**29.7**
14	**22.8**	**20.4**	**19.4**	**23.0**	**23.2**	**28.5**	**29.9**
16	**22.8**	**21.0**	19.6	**23.8**	**23.6**	**28.4**	**30.0**
18	**23.0**	**21.6**	**20.3**	**24.3**	**24.0**	**28.6**	**30.2**
20	**23.4**	**22.1**	**21.2**	**24.8**	**24.6**	**28.8**	**30.4**
22	**23.7**	22.6	22.0	**25.3**	**25.1**	29.6	**30.6**
24	**24.1**	23.0	22.9	**25.8**	25.6	30.4	30.8
26	**24.4**	**23.4**	23.6	**26.2**	26.0	30.6	31.0
28	**24.8**	23.8	24.1	**26.5**	26.4	31.0	31.2
30	**25.2**	24.2	24.6	**26.8**	26.7	31.9	31.3
35	26.0	25.3	25.3	27.5	27.5	34.6	31.5
40	26.6	26.2	26.0	28.2	28.1	35.4	31.8

Reports.—The observer's localizations and reports upon quality show that the spatial-qualitative patterns are identical with those previously found with the double-walled tube.[13] Both cold and warmth tend to spread up toward the throat in a diffuse pattern like that of esophageal temperature; but there is added a concrete, definitely localized, thermal sensation, lower down than the esophagal complex extends.[14] In three out of four cases when a recurrence of the thermal sensations was recorded the second sensation was referred farther down, an observation which suggested that localization might indicate the course of the stimulus to the pyloric end of the stomach.[15]

This hypothesis was supported by the results of a few trials. Twenty-five cc. of water at 60° C were introduced through a double-walled tube three times with the end of the tube at 40 cm. from the teeth (lower end of the esophagus), three

[13] *Op. cit.*, 42f.

[14] *Op. cit.*; compare Figg. 4-8, 20-24, 36-50 (p. 20) with Figg. 109-112, 117-120 (p. 42).

[15] A striking illustration of the shift of reference of a stomachic warmth in accordance with the position of the stomach is shown in Fig. 121, *op. cit.*, 42.

times at 50 cm. (cardiac end of stomach), and three times at 60 cm. (pyloric end,—unless the tube gets unusually kinked in the stomach). The observer (B) localized the lowest point of reference of the resultant warmth. The localizations (in terms of a centimeter scale of rectilinear body-coördinates in which " 40," *e. g.,* is a point on the surface of the body directly over a point in the esophagus which is 40 cm., measured along a stomach-tube, from the teeth[16]) are as follows:

Distance of end of tube from teeth.....	40 cm.	50 cm.	60 cm.
Av. longitudinal localization.....	42.8 ±2.5	51.3 ±3.4	56.2 ±5.3
Av. transverse displacement.....	0 ±0	Left, 1.1 ±0.4	Right, 2.2 ±3.7

A larger number of observations would give more reliable results. The indication is definite, however, that localization —at least with a practised observer—may serve as a basis for differentiation of stomachic from esophageal warmth.

Conduction Through the Body-Wall.—In order to discover whether the introduction of water at extreme temperatures has any sensible effect upon the temperature of the abdominal skin a trial was arranged in which a thermometer, reading to 0.1° C, was bandaged against the skin. The bulb, 3 cm. long, was placed on the median line of the body from the points 48 to 51 (scale of body-coördinates). It was covered by a piece of felt, 10 cm. square, over which was placed a large cotton pad. A heavy bandage, 25 cm. wide, was then wrapped tightly six times around the body. The thermometer extended from underneath the bandage so that the part of the scale showing body-temperature could be read. The readings could be made accurately to less than a scale division by an experimenter who, at the moment of reading, held a pocket flash-light behind the level of the top of the column. As the bandages warmed up the mercury rose. Finally it recorded 36.9° C. It had taken over five minutes to rise the last 0.1°. At this point a second experimenter pumped 500 cc. of water at approximately 0° C into the stomach through a stomach-tube which extended 50 cm. from the teeth. It required at least a minute to get the water in. About midway in the course of the introduction of the stimulus the mercury slowly began to fall and continued until it reached 36.85°, where it remained until some time after the cold water had all been introduced. Then it gradually rose again to 36.9°.

[16] *Cf.* Plate II, *op. cit.,* opp. p. 12.

The warming of 500 cc. of ice water to body-temperature (18,500 calories) had produced a maximal change of temperature in an optimally situated point on the skin of 0.05° C.[17]

Conclusions.—We have seen that the sensations arising upon thermal stimulation of the stomach have been attributed by different writers to the body-wall, to the esophagus, or to the stomach itself.

1. *The case against the body-wall.*

a. The sensations can not come from the abdominal skin. If 500 cc. of water at 0° C produce only 0.05° drop in the skin, it is out of the question that 25 cc. at 27° should arouse cutaneous sensation.[18] Just how deep the organs must lie it is difficult to say. One can only guess at the curve of transfer of heat for living tissue, in which the tendency of the circulating blood is to keep the temperature constant. In general one would expect that the effect of a thermal stimulus would not be very far-reaching, and the very small effect that we have found at the surface of the body supports such a view. The organs are probably not only not in the skin, but also very much more immediate to the stomach than they are to the superficial dermal layers.

b. The argument that the temperature-organs are stimulated only by conduction from the stomach, because the adequate temperatures are extreme and because sensation occurs after a latent time, is not borne out by fact. The adequate stimulus within the stomach may be less than five degrees above or ten degrees below body-temperature (p. 493). The water stimulus, in passing through the tube, in mixing with the stomachic contents (there is possibly always some content), and in getting into intimate contact with the walls of the stomach, approaches more nearly to the temperature of the body than had been supposed. The interpolation of these same factors also accounts for the apparent latent time, which is really a time that elapses before the stimulus has come intimately into contact with the gastric tissues.

2. *The case against the esophagus.*

a. The introspections show in general that the spatial-qualitative pattern is like the stomachic patterns obtained with a

[17] Previous trials with the thermo-couple bandaged against the skin had given negative results; but the galvanometer-scale could not easily be read to less than 0.1°C. Dr. S. I. Franz suggested the use of the thermometer.

[18] Hertz, Cook, and Schlesinger have argued against the origination of these sensations in the body-wall. *Op. cit.*, 484.

double-walled tube and unlike the esophageal patterns obtained in that manner. On the general basis of the identical character of the experiences we are entitled to assume that the results with the single-walled tube are as valid indicators of true stomachic sensation as are the previous results with the double-walled tube.

b. More specifically we have reason to believe that the localization of warmth or cold at a point considerably below the average lowest point for the corresponding esophageal sensation is a fairly reliable indicator that warmth or cold arises, not in the esophagus, but in an inferior region.

If neither the more superficial abdominal tissue nor the esophagus mediates these sensations, we must conclude that *the warmth and cold which arise from thermal stimulation of the stomach originate in organs lying either in the tissues of the stomach itself or in regions nearer to the stomach than the outer layers of the body-wall.* In this sense we may speak of ' stomachic warmth ' or of ' stomachic cold.'

Degree of Sensitivity of the Stomach.—It should be possible to make some statement with regard to the stimulus-limens of stomachic warmth and cold. Below are given average values—each one is a mean of all seven trials—for (*a*) the temperature at which the thermal sensation was first noted; (*b*) the temperature at which, after being noted, the sensation first disappeared; (*c*) the temperature, in the case of a recurrence after a first disappearance, at which the temperature last disappeared; and (*d*) the least extreme temperature at which the sensation was noted in the given trial.[19]

	(a) First Appearance	(b) First Disappearance	(c) Last Disappearance	(d) Least Extreme
Warmth....	39.7	40.9	40.4	39.6
	±1.04	± .73	± .43	± .91
Cold.....	29.5	25.7	26.1	30.0
	±4.21	±2.73	±2.49	3.69

Any one of these values might be taken as a limen. The (*a*) figures are subject to the error incurred in reading the galvanometer-scale when it was changing very rapidly. The large M. V., which is larger with the rapid change for cold than with the slower change for warmth, supports this view. The figures under (*c*) include temperatures taken at the cardiac end of the stomach for sensations felt at the pyloric

[19] The values are taken from the platted curves, not from the selected values of Tables I and II.

end. We should not be wise to accept figures which are known to apply to different conditions. The values given last, (*d*), include both the errors just mentioned. Nevertheless we can not take the results under (*b*) as representative, because in these there has been time for adaptation to set in. That adaptation may be very rapidly effective is suggested by the fact that the average value for the first disappearance of cold is 25.7° C, whereas in a single case (C7) cold was elicited by water which was only 27° before introduction and which brought the stomach contents down only to 29.5°. We may best suspend judgment, with the general statement that stomachic warmth may be brought out by a stimulus of about 40° C and stomachic cold by a stimulus of about 30° C.[20]

Summary.—A sensation of warmth is produced by a stimulus applied to the stomach at approximately 40° C; a sensation of cold is produced by a stimulus applied at approximately 30° C.

These thermal sensations arise either in the stomach itself or in tissues more immediately adjacent to the stomach than are the outer abdominal wall and the esophagus.

[20] The contention of Head that "epicritic" sensibility is not possessed by the viscera would seem, on the basis of these results, to find an exception in the case of the stomach.